# Viscosity of gaseous R404A, R407C, R410A and R507

H. Nabizadeh <sup>2,3</sup> and F. Mayinger <sup>2</sup>

-----

Paper presented at the Thirteenth Symposium on Thermophysical Properties, June 22-27, 1997, Boulder, Colorado, U.S.A.

<sup>&</sup>lt;sup>2</sup> Lehrstuhl A für Thermodynamik, Technische Universität München, 85747-Garching, Germany.

 $<sup>^{\</sup>rm 3}$   $\,$  To whom correspondence should be addressed.

**ABSTRACT** 

This Paper presents new measurements of the viscosity of gaseous **R404A** (52%

R143a, 44% R125, 4% R134a), **R407C** (23% R32, 25% R125, 52% R143a), **R410A** 

(50% R32, 50% R125) and **R507** (50% R143a, 50% R125). These mixtures are

recommended as substitutes for the refrigerants R22, R502 and R13B1. Measurements

have been carried out in an oscillating-disk viscometer. The obtained values of the

viscosity are relative to the viscosity of nitrogen. The experiments were performed at

atmospheric pressure in the temperature range 297-403 K and near the saturation line up

to pressures of 0.6  $P_{crit}$ . The estimated accuracy of the reported viscosities is  $\pm 0.5\%$  for

the atmospheric viscosities and  $\pm 1\%$  near the saturation line, being limited partly by the

accuracy of the available vapor pressure and the density data. The experimental

viscosities at atmospheric pressure are employed to determine the potential parameters S

and e which secure the optimum representation of the data with the aid of the extended

law of corresponding states developed by Kestin, Ro and Wakeham. A comparison of

the experimental viscosity data with the values calculated by the program REFPROP

both at atmospheric pressure and along the saturation line will be shown in this work.

KEY WORDS: gaseous; refrigerants; saturation; viscosity

2

#### 1. INTRODUCTION

The refrigerants R22, R502 and R13B1, which are used as working fluids for different refrigeration applications, will be restricted or completely phased out in near future. The potential alternatives recommended by the industry are either binary mixtures R410A (50% R32, 50% R125) and R507 (49.91% R143a, 50.09% R125) or the ternary mixtures R404A (52% R143a, 44% R125, 4% R134a) and R407C (23% R32, 25.1% R125, 51.6 % R134a). In this paper we present the viscosities of these mixtures in the gaseous phase. The mixtures are treated as quasi pure substances and the presented data are valid for the given compositions. The viscosity data consist of the viscosity at low pressure ( atmospheric pressure) and the viscosity values along four subcritical isotherms at pressures ranging from atmospheric to near the saturation pressure for the vapor phase of each substance. With knowledge of the vapor pressure and the extraplation of the isotherms up to the saturation conditions the viscosity along the saturation line can be determined with reasonable accuracy. The accuracy is partly limited by uncertainties of the density and the vapor pressure data which have been used for the evaluation of the viscosity values.

## 2. EXPERIMENTS

The measurements were perforemed in an oscillating-disk viscometer as it was used for our earlier viscosity measurements. The basic features and the principle of calibration of the viscometer are described in detail in references [1,2,3]. According to the theory of the measurement with an oscillating-disk viscometer [4-7], for a disk with finite diameter, edge effects have to be taken into account which only depend on system geometry. However, even with using corrections for these effects, absolute

measurements are only possible as long as the thickness of the boundary layer d at the oscillating-disk is larger than the distance between the fixed plates defined as

$$d = \left(\frac{h \cdot t_0}{2 \cdot p \cdot r}\right)^{1/2} >> b_1 + b_2 + d$$
 (1)

where, h is the viscosity and r the density of the fluid,  $t_0$  the period of oscillation in vacuum,  $b_1$  and  $b_2$  the distances between the oscillating-disk and the upper and lower fixed plates and d the thickness of the oscillating-disk. For the refrigerants, due to the geometrical arrangment of our viscometer ( $b_1 + b_2 + d \approx 3.521$  mm), condition (1) is satisfied only for viscosity meaurements at low pressures. At high pressures and the corresponding high densities of the refrigerants, condition (1) can not be kept anymore. Therefore, we have to evaluate the present experiments on the relative method suggested by Kestin *et al.* [5,6,7]. Prior to the viscosity measurements, the viscometer was calibrated with nitrogen in order to determine the edge-correction factor as a function of boundary layer thickness. The viscosity values of nitrogen were taken from reference [8]. The calibrations were performed at the same temperatures at which the viscosity was to be investigated [2].

The refrigerants R507 and R410A were supplied by Solvay Fluor und Derivate GmbH, FRG. R407C (99.7%) was supplied by ICI Chemicals & Polymers LTD, UK. R404A (99.67%) was supplied by Hoechst Chemikalien, FRG. The density values of the fluids were evaluated with the aid of the correlations of Döring and Buchwald [9,10] for R507 and R410A, with the equation of KLEA [11] for R407C and for R404A with the Prediction Program REFPROP (v.5) [12].

1

#### 3. RESULTS

#### 3.1. VISCOSITY AT LOW PRESSURE

In order to extend the measurements over a wide range of temperature the viscosities at low pressure have been measured separately. The experiments were performed at atmospheric pressure. The temperatures ranged from 298 - 400 K in the vapor phase. The results of the present experiments on the mixtures R404A, R407C, R410A and R507 are listed in Table I.

The low pressure viscosity  $h_0$  of the investigated mixtures can well be represented by the Chapman-Enskog equation derived from the kinetic theory for dilutegases.

$$h_0 = \frac{5}{16} \cdot \frac{(M \cdot \frac{k}{p \cdot N_0} \cdot T)^{1/2}}{s^2 \cdot \Omega_h(T^*)} = 2,6696 \cdot 10^{-2} \cdot \frac{(M \cdot T)^{1/2}}{s^2 \cdot \Omega_h(T^*)}$$
(2)

In equation (1) are:  $k=1,38066\cdot 10^{-23}~[~J\cdot K^{-1}~]$  the Boltzman-constant, M the molar mass [ kg·kmol<sup>-1</sup>],  $N_0=6,02204\cdot 10^{26}~[{\rm kmol}^{-1}]$  the Avogadro-number,  $\Omega_{\rm h}(T^*)$  the collision integral,  $T^*=k\cdot T/{\rm e}$  the reduced temperature, T [K] the absolut temperature,  $h_0$  [µPa·s] the viscosity, s and e the characteristic potential parameters with the units length and energy. For the collission integral  $\Omega_{\rm h}(T^*)$  we have used the following equation presented by Kestin, RO und Wakeham [13].

$$\Omega_{h}(T^{*}) = \exp[0.45667 - 0.53955.(\ln T^{*}) + 0.187265 (\ln T^{*})^{2} - 0.03629(\ln T^{*})^{3} + 0.00241(\ln T^{*})^{4}]$$
(3)

The parameters s and e, respectively  $\frac{e}{k}$ , can be determined by the low pressure viscosity data [14]. Table II gives the optimum values of the parameters s and e

\_

Table I. Viscosity of gaseous R404A, R407C, R410A and R507 at atmospheric pressure

Т	r	h <sub>o</sub>	T	r	$h_0$
(K)	$(kg \cdot m^{-3})$	(μPa⋅s)	(K)	$(kg \cdot m^{-3})$	(μPa⋅s)
	R404A			R407C	
305.50	3.770	12.398	297.65	3.533	12.207
313.57	3.669	12.726	314.66	3.334	13.014
323.45	3.485	13.125	324.74	3.227	13.459
332.87	3.511	13.500	333.15	3.143	13.716
334.11	3.370	13.550	365.96	2.853	15.101
364.62	3.196	14.740	398.79	2.693	16.519
392.59	2.963	15.799	398.83	2.613	16.558
	R410A			R507	
298.98	2.956	12.965	299.23	4.038	12.239
303.94	2.906	13.143	303.54	3.977	12.431
314.34	2.806	13.571	313.81	3.840	12.819
320.33	2.752	13.847	322.24	3.734	13.178
327.53	2.689	14.157	324.26	3.413	14.367
336.14	2.618	14.532	351.45	3.413	14.367
343.83	2.558	14.868	384.54	3.120	15.689
377.64	2.324	16.368	401.07	2.981	16.245
397.39	2.158	17.195			

The deviation of the experimental data from the calculated values with equation (1), baseline with 0% deviation, are shown in figure 1. The viscosity of the investigated fluids

can be represented by equation (1) and the values of the parameters s and  $\frac{e}{k}$ , shown in table II, with a maximum deviation of  $\pm 0.5$  %. The average deviation is in the order of  $\pm 0.3$ %. With respect to the theoretical background of equation (1), we assume that the viscosity values can be extrapolated below the investigated temperature range with only a modest loss of accuracy.

Table II. Potential parameters  $\frac{e}{k}$  and s for R404A, R407C R410A and R507 obtained from the viscosity measurements

Refrigerant	<u>e</u> k	S
Kenigeran	(K)	(nm)
R404A	279.31	0.4968
R407C	339.72	0.4538
R410A	317.47	0.4324
R507	294.33	0.4902

There is one set of experimental viscosity data at atmospheric pressure for the refrigerant R404A (SUVA HP62). The result of this experiment has been published by Du Pont [15] in form of an equation for temperatures between 253 and 423 K. To our knowledge, there are no further experimental data in the literature for the other subtances investigated in this work. Besides the equation of Du Pont for R404A, we have used the viscosity values calculated with the program REFPROP [12] to compare our results. Figure 2 shows the deviations of the viscosities taken from references [12] and [15] from the best fit of the experimental data represented by equation (1) as the

Fig. 1. Deviation of measured viscosity of refrigerants R404A,R407C, R410A and R507at atmospheric pressure from the viscosity calculated by Eq.(2), as a function of temperature.

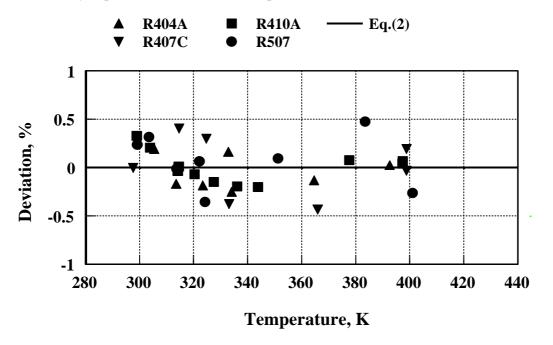
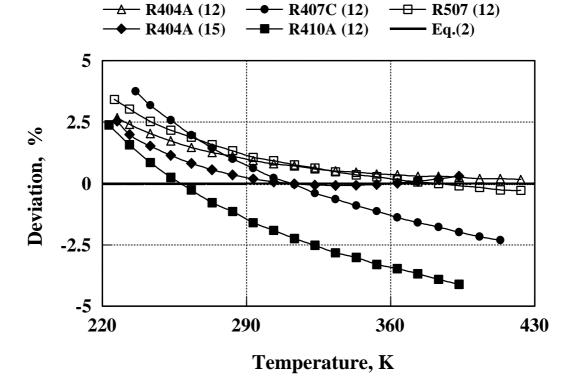


Fig. 2. Comparison between the present measurments of the viscosity of R404A, R407C, R410A and R507 at atmospheric pressure represented by Eq.(2) and the calculated values with REFPROP program [12] and Du pont values for R404A[15].



baseline. Above temperatures of 280 K the agreement between the viscosity values For R404A of DU PONT and REFPROP with the present data are within  $\pm 1\%$ . For the extrapolated values for temperatures below 280 K the differences increase to a maximum of  $\pm 2.5\%$ . The agreement between the experimental data of R507 and the calculated viscosities of [12] is also within  $\pm 1\%$  for temperatures over 290 K. Below this temperature the differences increase up to  $\pm 3.5\%$ . Although the estimated viscosities of reference [12] for R404A and R507 agree well with the present data, the predicted viscosities for R407C and R410A show a distinctively different temperature slope with deviations rising up to  $\pm 4\%$ . This might be the influence of the common polar component R32 (polarity  $\approx 2$  D) of the mixtures.

#### 3.2. THE VISCOSITY ALONG THE SATURATION LINE

Measurement of the viscosity exactly at the saturated conditions with an oscillating-disk viscometer is not possible. Beacause even a small droplet or undefineable amount of the condensated vapor on the oscillating disk will change its weight and consequently the moment of inertia of the suspension system. This is a significant parameter either for the calibration of the viscometer [5] or evaluation of the measured viscosity and must be known very exactly. Nevertheless, to obtain viscosity values along the saturation line in the vapor phase with an oscillating-disk viscometer, we first have neasured the viscosity in the superheated vapor along isotherms as a function of pressure. From the extrapolation of the isotherms up to the dew pressure we then estimate the viscosity values on the saturation line.

In the present work, four isotherms have been investigated for each substance.

The pressure was varied from atmospheric pressure up to pressures near saturation conditions. To avoid uncertainties of the measurements near the critical region, the

highest isotherm was selected to be at least 10 K below the critical isotherm. The results of the experiments on the fluids R404A, R407C, R410A and R507 in superheated vapor are given in tables III to VI in terms of pressure and nominal isotherms. The primary values of the measured viscosities were corrected for the nominal isotherms by means of the linear dependency of low pressure viscosity upon temperature which is already known from the measurements at low pressure. The corrections did not exceed 0.08% for all experimental values. Tables III and IV also contain the densities which have been used for the evaluation of the present measurements. Based on these density values, the uncertainty in the reported data is estimated to be  $\pm 0.6\%$  in the vapor phase.

Table III. Viscosity of gaseous  $\,R404A$  at nominal isotherms  $T_n$ 

p	r	h	p	r	h
(MPa)	$(kg \cdot m^{-3})$	$(\mu Pa\cdot s)$	(MPa)	$(kg \cdot m^{-3})$	$(\mu Pa \cdot s)$
	Tn=303.15			Tn=313.15	
	K			K	
0.101	3.86	12.32	0.101	3.74	12.69
0.339	13.89	12.39	0.382	15.15	12.78
0.693	30.29	12.60	0.815	34.67	13.07
1.096	52.52	12.99	1.256	58.53	13.47
1.299	66.08	13.22	1.59	81.14	13.96
1.378	71.94	13.30	1.759	94.96	14.36
1.417	75.03	13.35	1.805	99.18	14.35
	Tn=323.15 K		<b>,</b>	Гл=333.15 К	
0.101	3.62	13.09	0.101	3.51	13.53
0.225	8.42	13.09	0.259	9.40	13.56
0.514	19.98	13.20	0.495	18.45	13.56
0.929	38.41	13.47	0.997	39.73	13.89
1.510	69.62	14.02	1.50	64.49	14.39
2.001	105.05	14.93	2.096	102.24	15.39
2.205	124.70	15.46	2.524	139.84	16.54
2.277	132.85	15.73	2.701	160.88	17.36
2.299	135.69	15.97	2.793	174.22	17.86
			2.827	179.84	18.10

Table IV. Viscosity of gaseous  $\,R407C$  at nominal isotherms  $T_n$ 

p	r	h	р	r	h
(MPa)	(kg⋅m <sup>-3</sup> )	(μPa⋅s)	(MPa)	(kg⋅m <sup>-3</sup> )	(μPa⋅s)
	T <sub>n</sub> =297.15 K			T <sub>n</sub> =314.15 K	
0.101	3.55	12.19	0.101	3.29	12.99
0.289	10.55	12.12	0.279	9.53	12.96
0.608	23.36	12.06	0.468	16.41	12.99
0.911	37.18	12.50	1.106	42.79	13.29
0.995	41.37	12.64	1.353	54.87	13.52
			1.481	61.77	13.72
			1.504	63.06	13.80
			1.531	64.59	13.83
	T <sub>n</sub> =323.15 K			T <sub>n</sub> =333.15 K	
0.101	3.25	13.40	0.101	3.15	13.70
0.291	9.66	13.39	0.332	10.71	13.74
0.459	15.54	13.41	0.736	24.80	13.86
0.815	28.88	13.61	1.160	41.20	14.18
1.156	43.07	13.87	1.508	56.34	14.44
1.456	57.08	14.07	1.962	79.28	14.95
1.676	68.56	14.22	2.273	98.26	15.41
1.796	75.39	14.42	2.412	108.10	15.81
1.889	81.04	14.65	2.446	110.66	15.83
1.974	86.57	14.75	2.501	115.01	16.04

Table V. Viscosity of gaseous R410A at nominal isotherms  $T_n$ 

p	r	h	p	r	h		
(MPa)	$(kg \cdot m^{-3})$	(μPa⋅s)	(MPa)	$(kg \cdot m^{-3})$	(μPa⋅s)		
	Tn=298.15 K		•	Г <i>n</i> =304.15 К			
0.101	2.92	12.89	0.101	2.863	13.19		
0.332	10.17	12.88	0.289	8.61	13.19		
0.606	19.29	12.96	0.472	14.36	13.21		
0.949	31.93	13.11	0.812	25.92	13.31		
1.287	46.18	13.33	1.172	39.62	13.49		
1.510	56.92	13.45	1.517	54.78	13.71		
1.610	62.21	13.51	1.682	62.92	13.89		
1.641	63.90	13.54	1.910	75.53	14.23		
	Tn=314.15 K		7	$T_n = 324.15 \text{ K}$			
0.101	2.77	13.57	0.101	2.72	13.98		
0.381	11.03	13.60	0.354	9.86	13.99		
0.650	19.46	13.70	0.828	24.23	14.18		
1.017	31.87	13.86	1.349	42.06	14.42		
1.400	46.41	14.04	1.801	59.82	14.76		
1.653	57.11	14.21	2.269	81.53	15.19		
2.009	74.41	14.52	2.668	104.36	15.82		
2.287	90.29	14.94	2.902	120.68	16.31		
2.407	98.26	15.19	3.002	128.73	16.48		
2.466	102.41	15.25	3.105	137.93	16.84		

Table VI. Viscosity of gaseous  $\,R507$  at nominal isotherms  $T_n$ 

p	r	h	p	r	h
(MPa)	$(kg \cdot m^{-3})$	$(\mu Pa \cdot s)$	(MPa)	$(kg \cdot m^{-3})$	(μPa⋅s)
	T <sub>n</sub> =299.15 K			T <sub>n</sub> =303.15 K	
0.101	3.98	12.24	0.101	3.94	12.41
0.372	15.74	12.22	0.215	8.72	12.42
0.719	32.59	12.55	0.390	16.28	12.51
1.099	54.80	12.90	0.642	28.07	12.69
1.210	62.40	12.96	1.019	48.39	12.99
1.271	66.89	13.06	1.330	68.91	13.33
			1.374	72.22	13.32
			1.412	75.19	13.39
	T <sub>n</sub> =313.15 K			T <sub>n</sub> =324.15 K	
0.101	3.81	12.79	0.101	3.71	13.20
0.367	14.67	12.87	0.386	14.86	13.29
0.720	30.46	13.58	0.581	22.97	13.37
1.240	58.27	13.58	1.001	42.23	13.70
1.542	78.13	13.97	1.300	57.92	13.99
1.684	89.15	14.22	1.603	76.05	14.44
1.762	95.82	14.43	2.082	112.79	15.36
1.819	101.06	14.47	2.287	134.26	16.11
1.855	104.54	14.61	2.321	138.23	16.22
			2.351	142.12	16.49

The determination of the viscosity along the saturation line is demonstrated in Fig.3, in which the viscosity isotherms of R404A at nominal temperatures 303.15, 313.15, 323,15 and 333.15 K of R404A, as a representative for the other subtances, are plotted as a function of pressure. The plot shows also the fitting curves of the measured points. The standard deviation between the primary and the corrected values did not exceed ±0.04%. From the intersection of the fitting curves and the saturation pressure (dew pressure), shown as the vertical line for each isotherm, the viscosity on the saturation line has been defined. For extrapolating the viscosity values at the saturation line to the lower temperatures two additional values have been estimated from the low pressure experiments. One at the dew temperature at normal pressure and the other at the inversion temperature which is expected to be

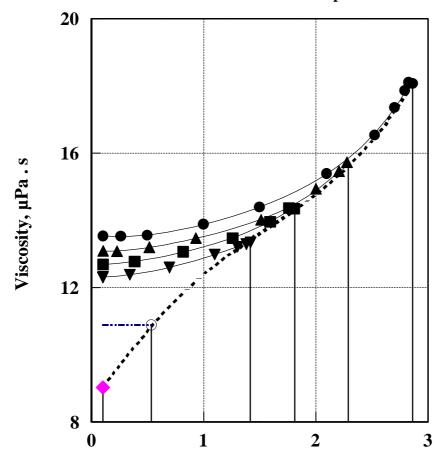
$$\frac{T_{inv}}{T_c} = T_r \approx 0.78 \tag{4}$$

for the refrigerants [1,2], where  $T_{inv}$  is the characteristic inversion temperature in K and  $T_r$  the critical temperature. The viscosities of refrigerants along the characteristic inversion isotherm are pressure independed. Hence, the viscosity at the saturation line and the viscosity at low pressure have the same value. With a hypothetical uncertainty of  $\pm 5$  K of the inversion temperature the corresponding viscosity value at saturation condition have an error less than  $\pm 2\%$ .

Table VII lists the viscosity data for the vapor phase of R404A,R407C, R410A and R507 at saturation conditions. The values of temperatures and the corresponding vapor pressures are taken from references [9-12].

Fig. 3. Experimental viscosity values of r404A at subcritical isotherms in the vapor phase as a function of pressure

▼ 303.15 K Saturated vapor line



Pressure, MPa

Table VII. Viscosity of R404A, R407C, R410A and R507 close to the saturation line obtained from the measurements in the vapor phase

T	p	h	T	p	h
(K)	(MPa)	(μPa⋅s)	(K)	(MPa)	(μPa⋅s)
	R404A			R407C	
226.75	0.101	9.032	236.05	0.101	9.374
269.28	0.532	10.886	280.19	0.584	11.417
303.15	1.413	13.323	297.15	0.987	12.630
313.15	1.811	14.349	313.15	1.539	13.800
323.15	2.289	15.733	323.15	1.989	14.820
333.15	2.862	18.122	333.15	2.535	16.230
	R410A			R507	
221.65	0.101	9.2135	226.66	0.101	9.029
269.05	0.704	11.499	268.30	0.530	10.884
298.15	1.663	13.570	299.15	1.307	13.120
304.15	1.945	14.310	303.15	1.450	13.510
314.15	2.495	15.650	313.15	1.860	14.750
324.15	3.153	17.210	323.15	2.354	16.950

For the purposes of practical use and comparison, the data have been correlated by an equation of the form

$$h_{s} = \frac{1}{z \cdot 10^{-5} \cdot \sum_{n=0}^{3} a_{n} \cdot \left(\frac{T}{T_{c}}\right)^{n}},$$
 (5)

where, T is the temperature in K,  $T_c$  the critical temperature in K,  $h_s$  the viscosity at saturation vapor in  $\mu$ Pa · s and Z the viscosity parameter in 1/Pa.s defined as[14]

$$Z = \frac{N_0^{1/3} \cdot (T_c \cdot R)}{M^{1/2} \cdot p_c^{2/3}}.$$
 (6)

M is the molar mass,  $N_0 = 6,02204 \cdot 10^{26}$  [kmol<sup>-1</sup>] the Avogadro-number, R = 8,314 [kJ·kmol<sup>-1</sup>·K<sup>-1</sup>] the gas constant and  $p_c$  the critical pressure. The value of Z and the coefficients  $a_0....a_3$  for each substance are shown in table VIII. The characteristic parameters of the fluids used in this work are included in Table IX.

Table VIII. Viscosity parameter  $\xi$  [14] and the coefficients  $a_0$  to  $a_3$  for the Eq.(5).

Refrigerant	ξ ( Pa·s ) <sup>-1</sup>	a <sub>0</sub>	a <sub>1</sub>	a 2	a 3
R404A	42429.18	1.4719	-4.2669	5.1983	-2.2972
R407C	39175.02	1.0514	-2.4759	2.7728	-1.2315
R410A	40990.75	1.2398	-3.3454	3.9880	-1.7793
R507	42170.05	2.0735	-6.6294	8.2936	-3.6473

Table IX. Characteristic Parameters for the Refrigeranrs R404A, R407C, R410A and R507 [9,10,11,12]

Refrigerant	M	$T_{c}$	$p_{c}$	$ ho_{ m c}$
	( kg·kmol <sup>-1</sup> )	(K)	(Mpa)	$(kg \cdot m^{-3})$
R404A	97.60	345.22	3.772	485.00
R407C	86.17	359.20	4.652	490.00
R410A	72.58	244.92	4.893	487.37
R507	98.86	343.96	3.717	494.25

Figure 4 shows the deviations of the experimenetal viscosity data from their calculated values by equation (5). The maximum devation lies within  $\pm 1.1\%$ , with an average deviation of  $\pm 0.65\%$ . To our knowledge, there are no other experimental data either in the vapor phase or along the saturation line for the substances investigated in present work. For a comparison with our data the corresponding viscosity values calculated with the program REFPROP [12] were used. Figure 5 shows the differences between the present viscosity data and the viscosities calculated with REFPROP. The experimental data in figure 5 are shown as the baseline represented by equation (5). figure 5 are shown as the baseline represented by equation (5). With an exception of R507 at the temperature 334 K (  $T_c$ =343.96 ), the agreement between our experimental data and the estimated values by REFPROP for the refrigerants R404A, R407C, R410A and R507 is within  $\pm 4$  %. The uncertainty in the prediction of the viscosity of refrigerants by REFPROP program is estimated as  $\pm 5$  %.[12].

Fig. 4. Comparison between the present experimental values of viscosity of R404A, R407C, R410A and R507 at the saturatied vapor line and their fitting curve represented by Eq.(5).

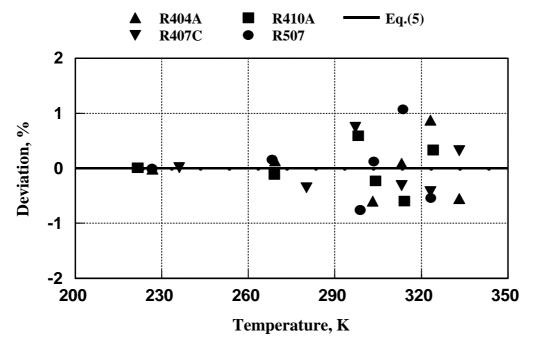
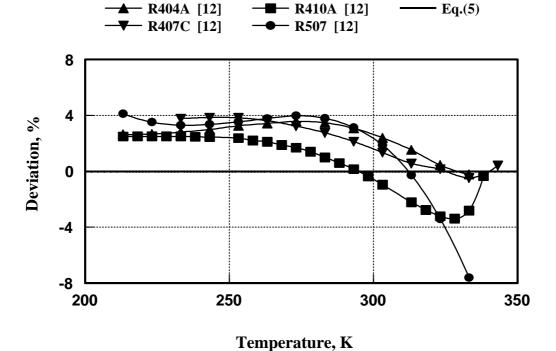


Fig. 5. Comparison between the present values of viscosity of R404A, R407C, R410A and R507 at the Saturated vapor line represented by Eq.(5) and the viscosities calculated with the programREFPROP [12].



## 4. CONCLUSION

The viscsity of the refrigerants R404A, R407C, R410A and R507 at low pressures can be represented with the aid of Chapman-Enskog equation with a mean deviation of  $\pm 0.3$  %. The charcteristic parameters s and  $\frac{e}{k}$  has been evaluated for the investigated refrigerants. The viscosities of these refrigerants at the saturation line have been evaluated by means of the measurments of the viscosity along the subcritical isotherms in the superheated vapor. The uncertainty of the viscosity along the saturation line, based on the used density data, amounts at maximum to  $\pm 1.1$ %, while the average deviation is  $\pm 0.65$ %.

## **ACKNOWLEDGEMENT**

The authors would like to express their gratitude to the Forschungsrat Kältetechnik e.v. for supporting this research project.

## **REFERENCES**

- 1. F. Mayinger and H. Nabizadeh, Deutsche Kälte- und Klimatech, 2:83 (1992).
- 2. H. Nabizadeh and F. Mayinger, Int. J. Thermophys. 10:701 (1989).
- 3: H. Nabizadeh and F. Mayinger, High Temperatures-High Pressures, 24:221 (1992).
- 4. G. F. Newell, ZAMP **10**:160 (1959)
- 5. J. Kestin. and H. E. Wang, *Physika* **26**:575 (1960).
- 6. J. Kestin, W. Leidenfrost and C. W. Liu, ZAMP 10:558 (1959).
- 7. J. Kestin, and J. H. Whitelaw, *Physika* **29**:335 (1963).
- 8. K. Stephan, R. Krauss and A. Laesecke, J. Phys. Chem. Ref. Data, 16:993 (1987).
- 9. R. Döring, H. Buchwald, and J. Hellmann, *Deutsche Kälte- und Klimatech*, **2**:29(1994).
- 10. R. Döring, and H. Buchwald, Deutsche Kälte- und Klimatech, 2:211(1994).
- 11. KLEA 66 (407C), *Thermodynamic Property Data for Klea 66*, ICI KLEA January 1994, (private communication).
- 12. M. Hubr, J. Gallagher, M. McLinden. and G. Morrison, *NIST Thermodynamic Properties of Refrigerants and Refrigerant Mixtures Database* (REFPROP), version 5.0 (1996).
- 13. J. Kestin, S. T. Ro, and W. Wakeham, *Physika* **58**:165 (1972).
- 14. J. B. Hirschfelder, C. F. Curtiss and R. B. Bird, The Molecular Theory of Gases and Liquids (John Wiley and Sons, Inc., New York. 1966), pp 514-631.
- 15. Du Pont, Production Information for Transport Property of SUVA HP 62 (R404A), May (1993). (private communication).